



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F402

Soil Bulk Density – Core Method

Standard Operating Procedure

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1. Purpose

This procedure describes the determination of soil bulk density using the volumetric core method. Bulk density (ρ_b) is the mass of oven-dried soil per unit volume of field-moist soil, expressed in g/cm³. It is used to convert gravimetric measurements (e.g., nutrient concentrations in mg/kg) to volumetric or areal bases (e.g., kg/ha), to assess soil compaction, to calculate total porosity, and to evaluate management effects on soil physical quality. The core method is the most widely used direct measurement of bulk density and is described in the SSSA Methods of Soil Analysis (Blake & Hartge, 1986; Grossman & Reinsch, 2002).

2. Scope

- **Applies to:** Mineral soils at all EA Program field sites, including agricultural plots, photovoltaic panel study sites, and restoration sites. Suitable for depths of 0–30 cm using hand-driven cores.
- **Does not apply to:** Soils with abundant coarse fragments (greater than approximately 20% by volume of gravel, cobbles, or stones), which require the excavation or clod method. Also not applicable to organic soils (histosols) or very loose sandy soils where core insertion causes compaction of the sample.
- **Location:** All EA Program field sites; laboratory drying and weighing in SGM 133

3. Responsibilities

Role	Responsibility
Lab PI	Approve sampling plan, ensure training compliance
Field Lead	Coordinate sampling logistics, verify equipment
Trained Personnel	Collect cores and process samples per this SOP
New Students	Complete training before independent sampling

4. Definitions

- **Bulk density (ρ_b):** The mass of oven-dry soil per unit volume of field-moist soil, including pore space; expressed in g cm⁻³ or Mg m⁻³; typically ranges from 1.0–1.8 g cm⁻³ for mineral soils and 0.1–0.5 g cm⁻³ for organic soils.
- **Coarse fragment correction:** An adjustment to bulk density calculations that removes the volume and mass of rock fragments (greater than 2 mm) from the core sample; required in stony or gravelly soils where coarse fragments occupy significant core volume.
- **Core sampler:** A thin-walled, beveled steel cylinder of known volume pushed into the soil to extract an intact sample for bulk density determination; internal dimensions must be measured and recorded for each sampler.

- **Dry bulk density:** The mass of oven-dry soil divided by the total volume of the sample including pore space; the standard reported value for bulk density; calculated after drying at 105 °C to constant mass.
- **Porosity (ϕ):** The fraction of total soil volume occupied by pores (air + water): $\phi = 1 - \rho_b / \rho_p$ where ρ_p is particle density (assumed 2.65 g cm⁻³ for mineral soils); porosity decreases as bulk density increases.
- **Soil carbon stock:** The mass of organic carbon per unit land area (Mg C ha⁻¹) calculated from bulk density, sampling depth, and organic carbon concentration; bulk density measurement is the primary source of uncertainty in carbon stock estimates.
- **Soil compaction:** An increase in bulk density caused by mechanical pressure (tillage, vehicle traffic, trampling); reduces porosity, impedes root growth, and decreases infiltration rates.

5. Safety and Hazards

Hazards

- **Physical:** Driving the core sampler with a mallet or hammer poses a risk of hand and finger injury. Trowels and soil knives are sharp. Repetitive hammering can cause strain.
- **Biological:** Soil-borne pathogens; wash hands thoroughly after handling soil. Tick and insect exposure at field sites.
- **Environmental:** Standard field hazards (heat, uneven terrain, sun exposure).

5.1. Required PPE

- ☐ Closed-toed shoes or field boots
- ☐ Nitrile or leather work gloves
- ☐ Safety glasses (when driving the sampler)
- ☐ Sun protection (hat, sunscreen)

5.2. Related SOPs

Refer to [SOP-F001 Field Safety](#) for general field safety procedures, including transportation, weather hazards, and emergency response.

6. Equipment and Materials

6.1. Field Equipment

Item	Notes
Bulk density core rings	Known internal volume; typical dimensions: 5 cm height x 5 cm diameter (approximately 98 cm ³) or 7.5 cm x 7.5 cm

Item	Notes
Core sampler (drive head)	Fits over the core ring; beveled cutting edge
Rubber mallet or dead-blow hammer	For driving the sampler
Driving cap or block	Wooden or rubber block to protect the sampler from mallet strikes
Flat-blade trowel or soil knife	For excavating around the core and trimming ends
Straight-edged blade or spatula	For trimming flush with ring ends
Plastic caps or aluminum foil	Two per core, to seal both ends after trimming
Pre-labeled ziplock bags	For transporting sealed cores
Cooler with ice packs	If gravimetric moisture will be determined separately
Ruler or depth gauge	For measuring insertion depth
Field notebook	For recording site, depth, and core ID
GPS unit or smartphone	For recording sampling coordinates

6.2. Laboratory Equipment

Item	Notes
Drying oven	Set to 105 C; see SOP-L105
Analytical balance	0.01 g resolution minimum; SOP-L102
Desiccator	For cooling dried samples before weighing
Pre-weighed aluminum drying tins	Large enough to hold the full core volume
Calipers or ruler	For verifying core ring dimensions

7. Procedure

7.1. Pre-Sampling Preparation

1. Measure and record the internal dimensions of each core ring (inside diameter and height) using calipers. Calculate the volume:

$$V = \pi \left(\frac{d}{2} \right)^2 \times h$$

where d = inside diameter (cm) and h = height (cm).

2. Pre-label core rings or bags with site name, plot ID, depth, and replicate number
3. Pre-weigh aluminum drying tins and record the tare mass
4. Clean core rings and the sampler with DI water before use
5. File a field work planning form per [SOP-F001](#)

7.2. Field Sampling

1. Navigate to the predetermined sampling location and record GPS coordinates
2. Clear surface litter, loose organic debris, and any vegetation from a small area (approximately 15 x 15 cm) at the sampling point without disturbing the mineral soil surface

Important

Do not compress or disturb the soil surface before inserting the core. The goal is to capture the soil at its natural field density.

3. Assemble the core ring inside the drive head. Ensure the beveled cutting edge faces downward.
4. Place the assembled sampler vertically on the soil surface
5. Position the driving cap or wooden block on top of the sampler
6. Drive the sampler into the soil using the mallet, applying steady, even blows. Drive until the top of the core ring is flush with, or slightly below, the soil surface.
7. Do not over-drive the sampler. If the ring is driven more than 1 cm past flush, the sample may be compacted and should be discarded. Over-driving and under-driving the core introduce bias in opposite directions; the magnitude of the bias depends on soil type and moisture status (Grossman & Reinsch, 2002; Page-Dumroese et al., 1999).
8. Carefully excavate the soil around the sampler using the trowel, leaving a pedestal of soil beneath and around the core
9. Slide the trowel or soil knife beneath the bottom of the core to sever it from the underlying soil
10. Lift the sampler and core out of the ground

7.3. Trimming and Capping

1. Remove the core ring from the drive head
2. Using a straight-edged blade, trim the soil flush with the top and bottom of the ring. Remove any material that extends beyond the ring face. Be careful not to smear or compress the soil.
3. If large roots or rocks protrude from the core face, note this in the field notebook. If coarse fragments constitute a substantial fraction of the core, record this and consider whether the core method is appropriate for this site.
4. Cap both ends of the ring with plastic caps or wrap tightly with aluminum foil
5. Place the capped core in a labeled ziplock bag
6. Store in the cooler for transport to the laboratory

Tip

Collect a minimum of three replicate cores per plot or treatment to account for spatial variability. Five replicates are preferred for statistical robustness, especially in heterogeneous soils or when detecting small differences between treatments.

7.4. Backfilling

Backfill the sampling hole with surrounding soil to minimize site disturbance and prevent tripping hazards.

7.5. Laboratory Processing

1. Remove the plastic caps or foil from the core
2. Transfer the entire soil core from the ring into a pre-weighed aluminum drying tin. Use a spatula or trowel to ensure all soil is transferred; scrape the inside of the ring if necessary.
3. Record the mass of the tin plus field-moist soil (this can also be used to calculate gravimetric moisture if a separate subsample is not taken)
4. Place the tin in the drying oven at 105 C for a minimum of 24 hours (until constant mass is achieved). See [SOP-L105](#).
5. Remove the tin from the oven and cool in a desiccator for 20–30 minutes
6. Weigh the tin plus oven-dried soil and record the mass

8. Quality Control and Acceptance Criteria

8.1. Calculations

Bulk density (g/cm³):

$$\rho_b = \frac{M_{\text{dry}}}{V_{\text{core}}}$$

where M_{dry} = mass of oven-dried soil (g) and V_{core} = internal volume of the core ring (cm³).

Gravimetric moisture content (if determined from the same core):

$$\theta_g = \frac{M_{\text{wet}} - M_{\text{dry}}}{M_{\text{dry}}}$$

where M_{wet} = mass of field-moist soil (g).

Total porosity (fraction):

$$\phi = 1 - \frac{\rho_b}{\rho_s}$$

where ρ_s is the particle density, typically assumed to be 2.65 g/cm³ for mineral soils. The assumed particle density of 2.65 g/cm³ is appropriate for most mineral soils but should be verified for soils with high organic matter (where it may be lower) or heavy mineral content (Blake & Hartge, 1986).

8.2. Expected Ranges

Typical bulk density values for mineral soils:

Soil Type	Expected ρ_b (g/cm ³)
Well-aggregated forest or prairie topsoil	0.8 – 1.2
Cultivated agricultural topsoil	1.1 – 1.5
Compacted or traffic-affected soil	1.5 – 1.8
Sandy subsoil	1.4 – 1.8
Clay-rich subsoil	1.1 – 1.6

Values outside the range of 0.5 – 2.0 g/cm³ for mineral soils should be investigated for sampling or measurement error.

Variability is typically higher in surface soils than in subsoils because of biological activity and tillage effects (Al-Shammmary et al., 2018). For carbon stock calculations, consistent sampling depth and core diameter are critical because small changes in bulk density propagate into large errors at the landscape scale (walter2016?).

8.3. QC Requirements

- Collect a minimum of three replicate cores per plot or treatment
- Calculate the coefficient of variation (CV) among replicates. A CV greater than 10% suggests high spatial variability or possible sampling problems (compaction, lost soil during extraction). Consider collecting additional replicates.
- Verify core ring dimensions at the start of each sampling campaign. If the ring is dented or deformed, replace it.
- Dry samples to constant mass. If the mass changes by more than 0.1 g between successive weighings (at least 4 hours apart), continue drying.

9. Waste Disposal

Waste Type	Disposal Method
Dried soil	Return to field site if uncontaminated, or standard trash
Used aluminum tins	Recycle or standard trash
Used gloves	Standard trash

10. References

Al-Shammmary, A. A. G., Kouzani, A. Z., Kaynak, A., Khoo, S. Y., Norton, M., & Gates, W. (2018). Soil bulk density estimation methods: A review. *Pedosphere*, 28(4), 581–596. [https://doi.org/10.1016/S1002-0160\(18\)60034-7](https://doi.org/10.1016/S1002-0160(18)60034-7)

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- Page-Dumroese, D. S., Jurgensen, M. F., Brown, R. E., & Mroz, G. D. (1999). Comparison of methods for determining bulk densities of rocky forest soils. *Soil Science Society of America Journal*, 63(2), 379–383. <https://doi.org/10.2136/sssaj1999.03615995006300020016x>

11. Training Record

Before collecting bulk density cores independently, personnel must:

1. Read this SOP in full
2. Complete [SOP-F001 Field Safety](#) training
3. Complete [SOP-F400 Soil Sampling](#) training
4. Observe a trained operator perform core collection, trimming, and laboratory processing
5. Demonstrate proper core driving technique, trimming to flush, and capping without compacting the sample
6. Process at least three replicate cores through drying and weighing with a CV below 10%
7. Be signed off by the field lead or PI

12. Appendix A: Example Calculation

```
# Bulk density calculation from core method
# Core ring dimensions
diameter_cm <- 5.0
height_cm <- 5.0
volume_cm3 <- pi * (diameter_cm / 2)^2 * height_cm

# Masses
tin_g <- 15.32           # Tare mass of aluminum tin
tin_wet_g <- 112.45      # Tin + field-moist soil
tin_dry_g <- 95.78       # Tin + oven-dried soil (105 C, 24 h)

# Calculations
mass_dry_g <- tin_dry_g - tin_g
mass_wet_g <- tin_wet_g - tin_g

bulk_density <- mass_dry_g / volume_cm3
grav_moisture <- (mass_wet_g - mass_dry_g) / mass_dry_g
porosity <- 1 - (bulk_density / 2.65)
```

```
cat(sprintf("Core volume:           %.2f cm3\n", volume_cm3))
cat(sprintf("Oven-dry soil mass:    %.2f g\n", mass_dry_g))
cat(sprintf("Bulk density:          %.2f g/cm3\n", bulk_density))
cat(sprintf("Gravimetric moisture:  %.3f g/g\n", grav_moisture))
cat(sprintf("Total porosity:         %.2f\n", porosity))
```

13. Appendix B: Coarse Fragment Correction

If the core contains gravel or rock fragments larger than 2 mm, the bulk density of the fine-earth fraction (less than 2 mm) can be calculated by removing the coarse fragments from the oven-dried sample, weighing them separately, and estimating their volume:

$$\rho_{b,\text{fine}} = \frac{M_{\text{dry}} - M_{\text{cf}}}{V_{\text{core}} - V_{\text{cf}}}$$

where M_{cf} = mass of coarse fragments (g) and V_{cf} = volume of coarse fragments (cm^3), estimated by water displacement or by dividing M_{cf} by an assumed rock density (typically 2.65 g/cm^3). The water-displacement method for estimating coarse-fragment volume is preferred when fragment shapes are irregular (Page-Dumroese et al., 1999).

Record the coarse fragment mass fraction and report whether the bulk density value refers to the whole soil or the fine-earth fraction.

14. Appendix C: Troubleshooting

Symptom	Probable Cause	Corrective Action
Core compacted during insertion	Soil too dry and hard; excessive force	Moisten the surface slightly (note in field notebook); do not hammer past flush
Soil falls out of the bottom	Loose sandy soil; insufficient cohesion	Try sampling when soil is slightly moist; use a core sampler with a retaining basket
Large roots fill the core	Heavily rooted location	Move to a nearby location; note the root density
CV among replicates exceeds 10%	High spatial variability; compaction artifacts	Collect additional replicates; inspect technique
Bulk density above 2.0 g/cm^3	Measurement error or rock fragment in core	Re-check masses and volume; inspect for gravel
Bulk density below 0.5 g/cm^3	Organic layer sampled; incomplete core	Verify that mineral soil was sampled; check for lost soil